An Object-Oriented Simulation Program for CMS

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Outline

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- Interfaces and services
- CMS detector simulation and validation
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OSCAR overview

Object Oriented **S**imulation for **C**MS **A**nalysis and **R**econstruction

- Full CMS simulation based on the Geant4 toolkit
- Geant4: physics processes describing in detail electro-magnetic an hadronic interactions; tools for the CMS detector geometry implementation; interfaces for tuning and monitoring particle trackin
- CMS framework: application control, persistency, common services and tools (magnetic field, generator interfaces and support for MC truth, infrastructure for hits and readout units,…), “action on demand” to selectively load desired modules, configure, tune application
- CMS changed from CMSIM/GEANT3 to OSCAR/GEANT4 end 2003;
- OSCAR used for substantial fraction of DC04 production; will be used fo physics TDR production
- CPU: OSCAR $\leq$ 1.5 x CMSIM - with lower production cuts!
- Memory: ~110 Mb/evt for pp in OSCAR $\approx$ 100 Mb in CMSIM
- Robustness: ~1/10000 crashes in pp events (mostly in hadronic physics) in DC04 production to 0 crashes in latest stress test (800K single particles, 300K full QCD events)

Interfaces and services

- Application steering handled by CMS framework; CMS RunManager implements functionality required for G4 running and provides handles to the G4 run, event, track and step - as required for application configuration and monitoring; manages random number and cross-section table storage and retrieval
- Detector geometry construction automated via Detector Description Database which converts input from XML files managed by Geometry project; XML files selected by user-defined configuration
- Generator input (via RawHepEvent CMS format and recently HepMC) converted to G4Event; specific generator type and event format (particle gun, Pythia, etc from ntuple, ASCII, database etc) run-time configurable
- Interface from CMS magnetic field services to G4; field selection run-time configurable; propagation parameters via XML
- Infrastructure for physics lists (run-time selection of list and process types, optional activation of γ/e-nuclear and synchrotron radiation,misc. customizations) and production cuts (the latter via XML)
- User actions (monitoring, tuning) via dispatcher-observer pattern for pointer to observable entity
- Persistency, histogramming, monitoring etc transparently through CMS framework (COBRA)

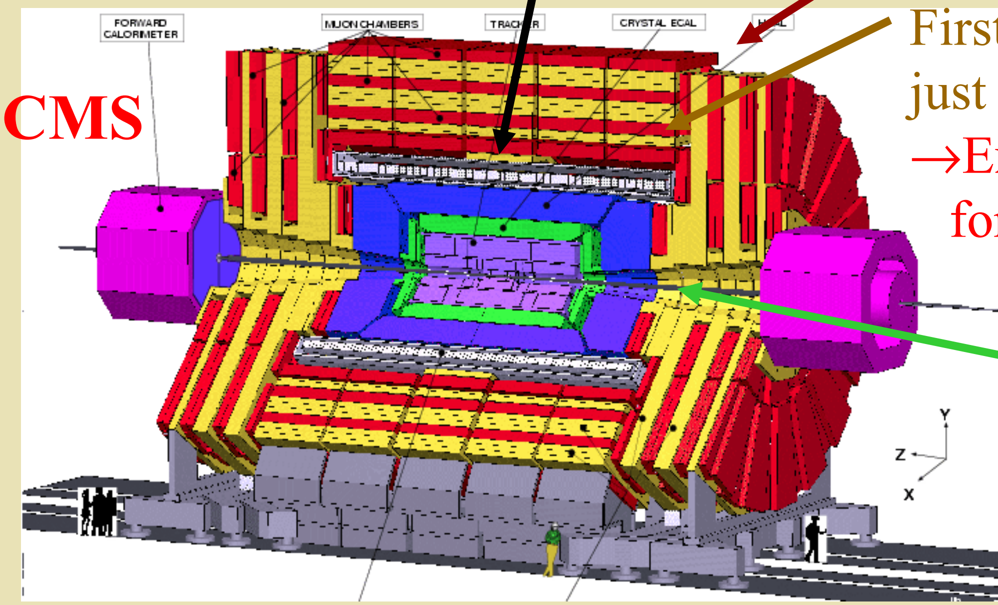
CMS Detector

> 1 M geometrical volumes;
> 12 M readout channels

13m x 6m Solenoid: 4 Tesla Field

→ Tracking up to h ~ 2.4

Muon system in return yoke

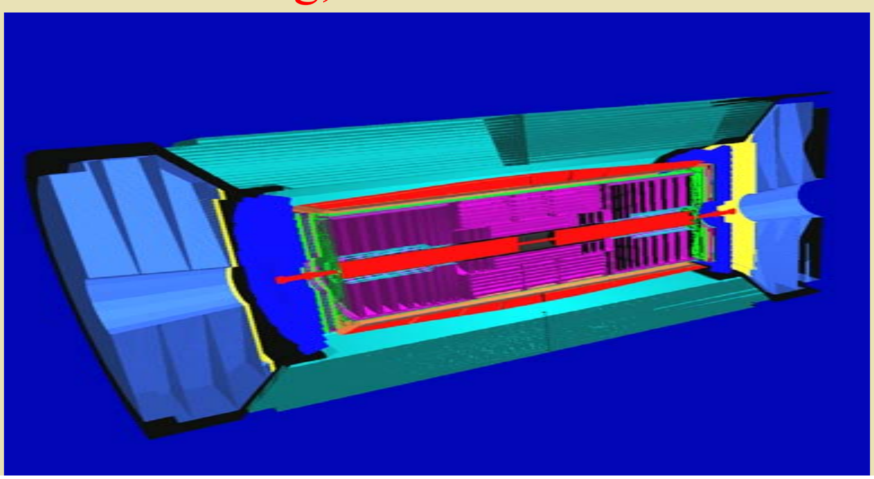


First muon chamber just after solenoid

→Extended lever arm for p_T measurement

ECAL & HCAL Inside solenoid

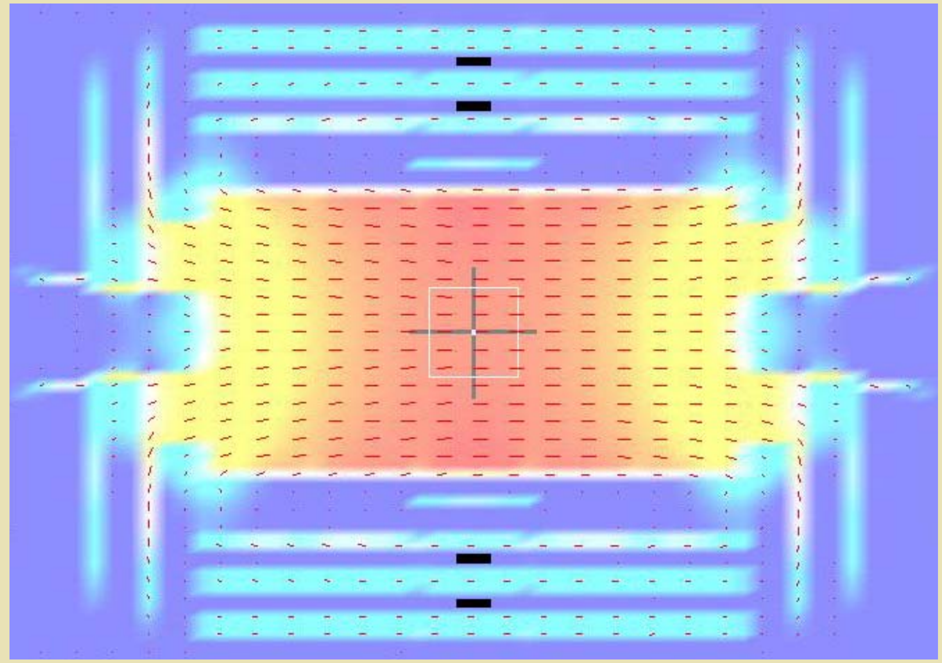
22m Long, 15m Diameter



Sliced view of CMS barrel

Magnetic Field

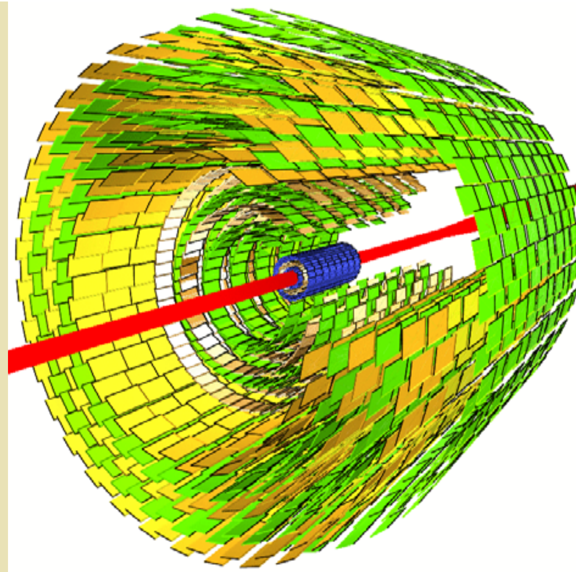
Field Map (TOSCA calculation)

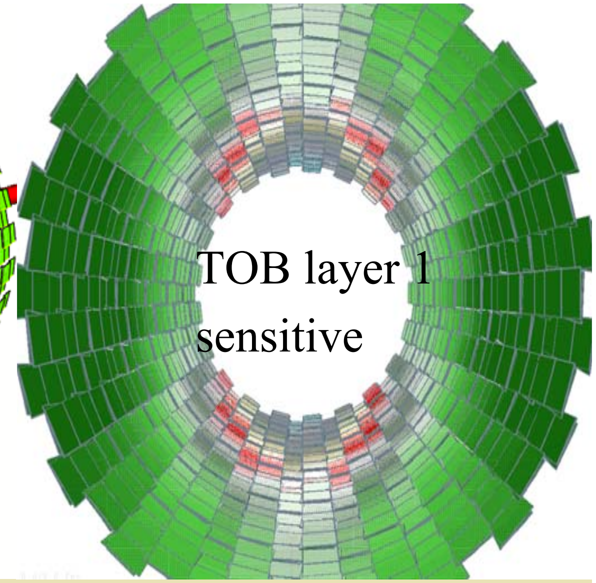


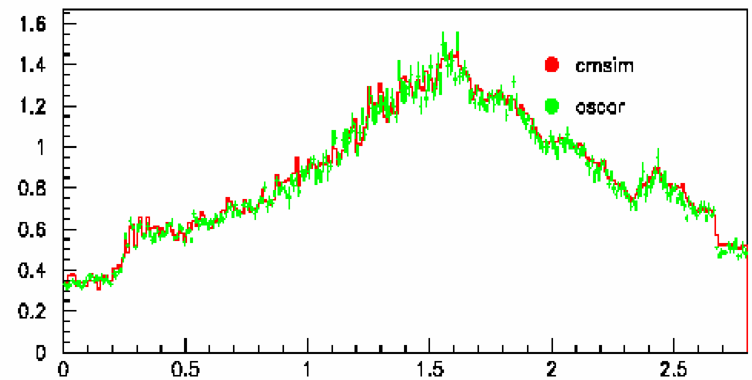
- Designed to optimize simulation and reconstruction
- Based on dedicated geometry of "magnetic volumes"
- Decouple volume finding and interpolation within a volume
- Time spent in <u>magnetic field query</u> (P4 2.8 GHz) for 10 minimum bias events (wit delta=1mm) 13.0 vs 23.6 s for G3/Fortran field
- ⇒ new field ~1.8-2 times faster than FORTRAN/G3
- GEANT4 volumes can be connected to corresponding magnetic volumes ⇒ avoid volume finding ⇒ potential ~2x improvement
- With G4, also possible to use local field managers for different detectors

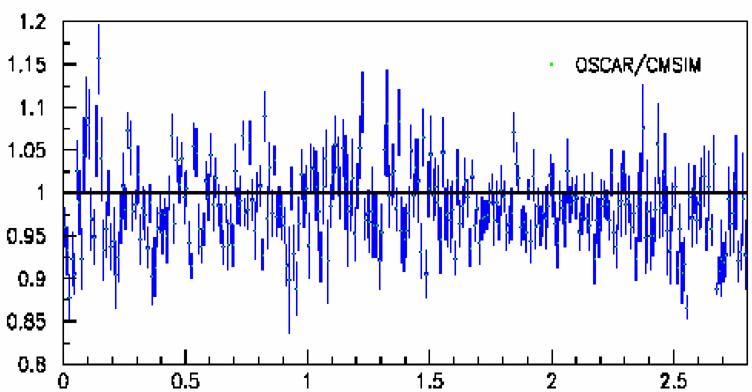
Tracker

Detailed description of all active and passive components; material budget









Critical requirements for physics studies with tracker

Correct, navigable Monte Carlo truth (particle, track, vertex, history) with trace-ability of initial primary particle

Special treatment of hard brem with the assignment of new track for electron above threshold (500 MeV)

⇒ Extensive validation in terms of tracking and hit distributions

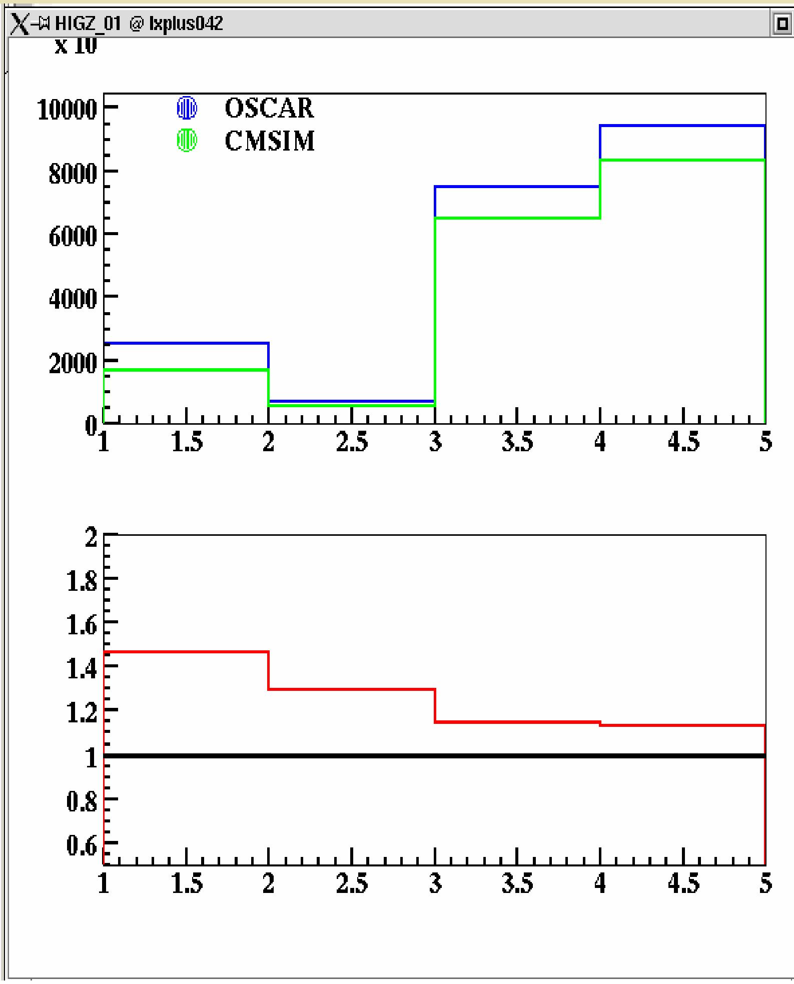
Hits from minimum bias events in Tracker

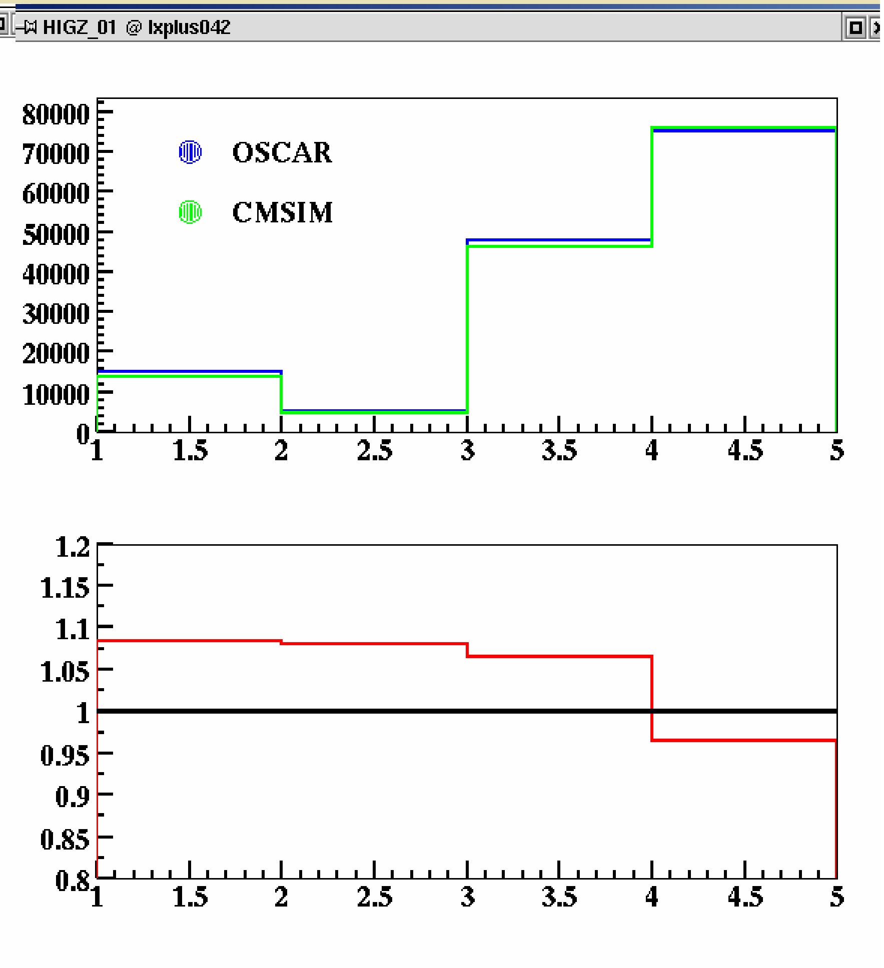
Pixel cut in G3 too high
 ⇒10% increase expected
 ±5% differences in Si not significant

PixelBarrel PixelEndcap SiBarrel SiEndcap

Raw simulated hits

Reconstructed hits





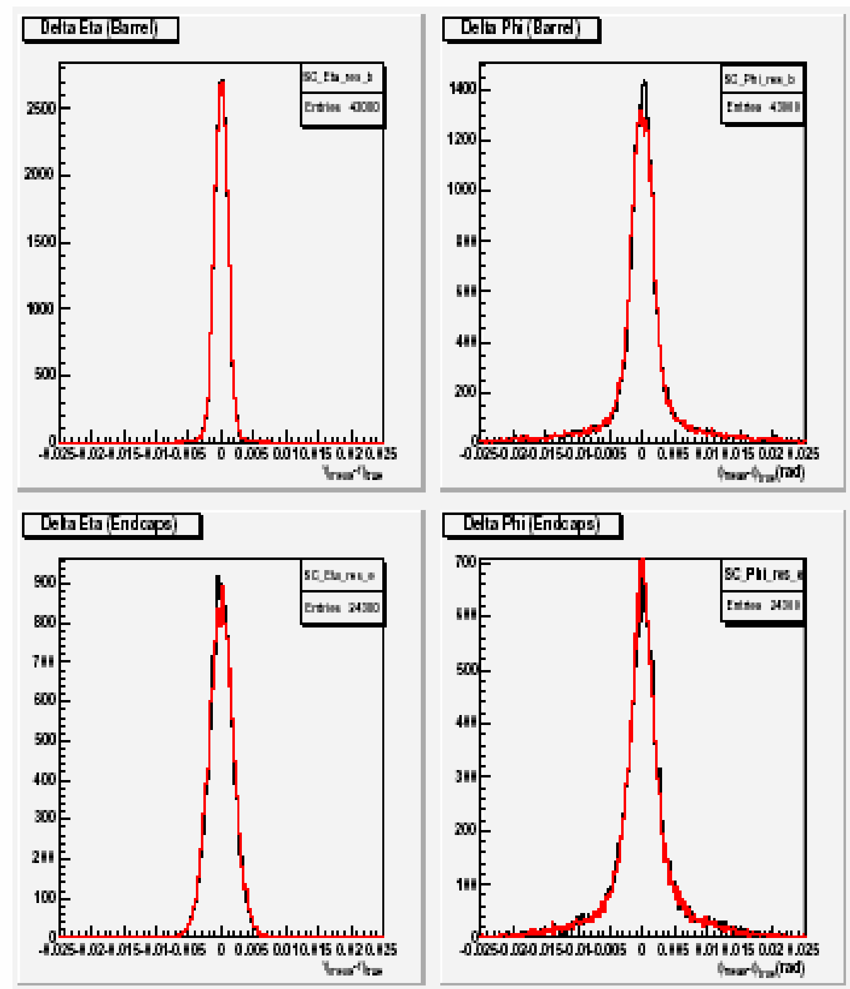
Electromagnetic Calorimeter (ECAL)

Comparisons with CMSIM/G3 and test beam data

- Energy and position resolution, shower shape
- Hadronic showers
- Level-1 e/m trigger response
- Preshower response
- Performance studies

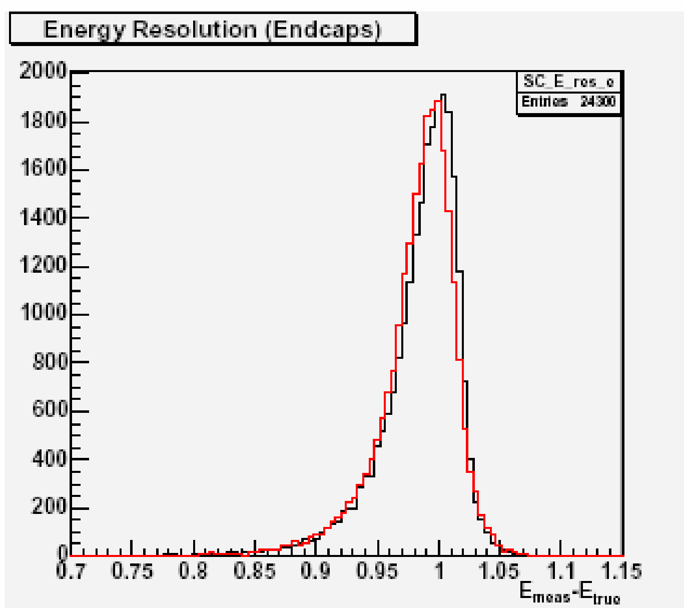
Position resolution

Red – OSCAR_2_3_0_pre5, black – CMS132



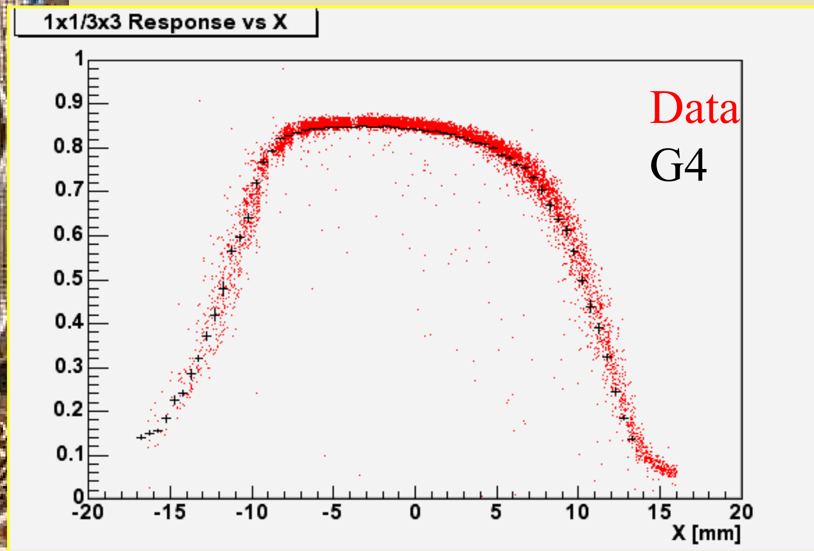
Energy resolution

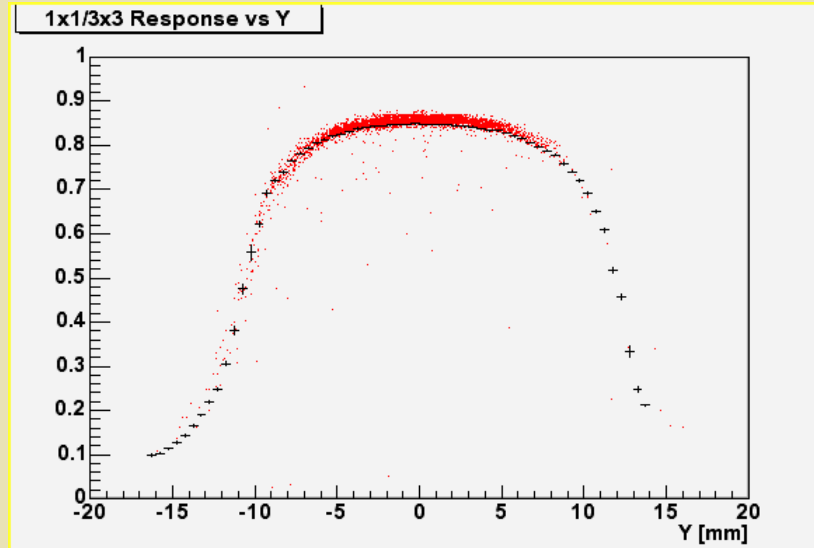
Endcap



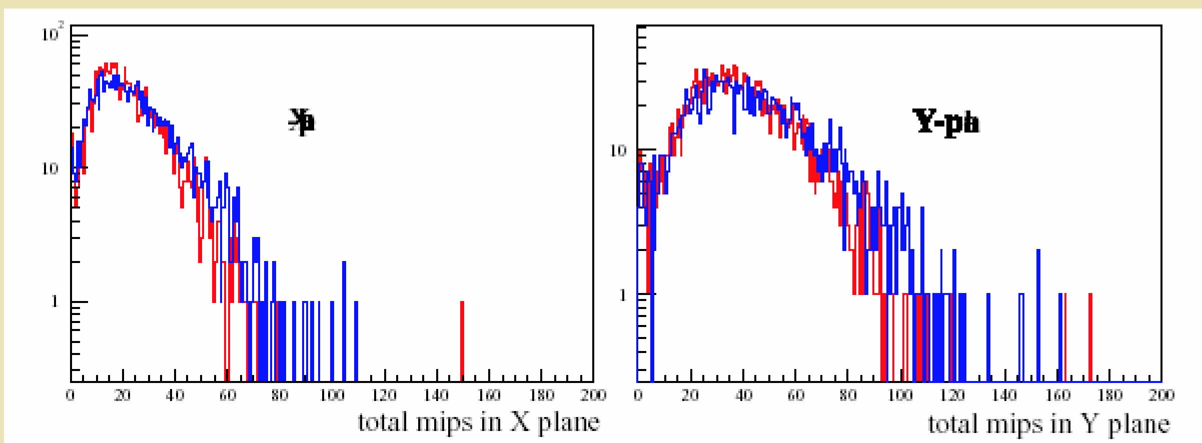
ECAL *cont'd*

Single crystal containment: E_{1x1}/E_{3x3} versus position



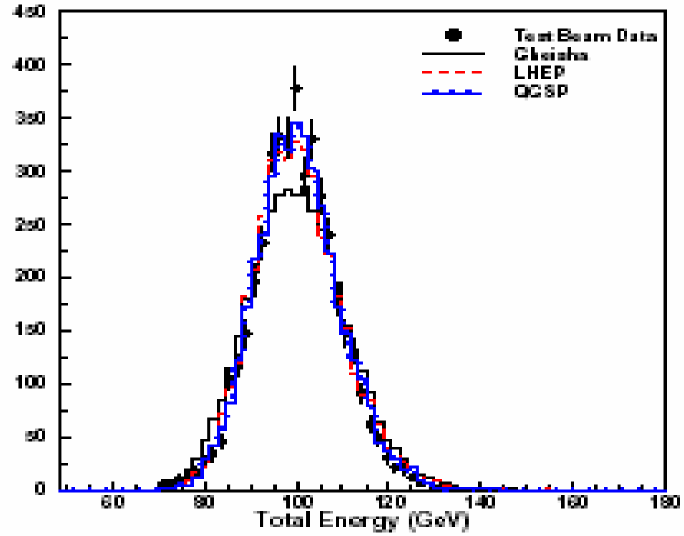


Preshower response

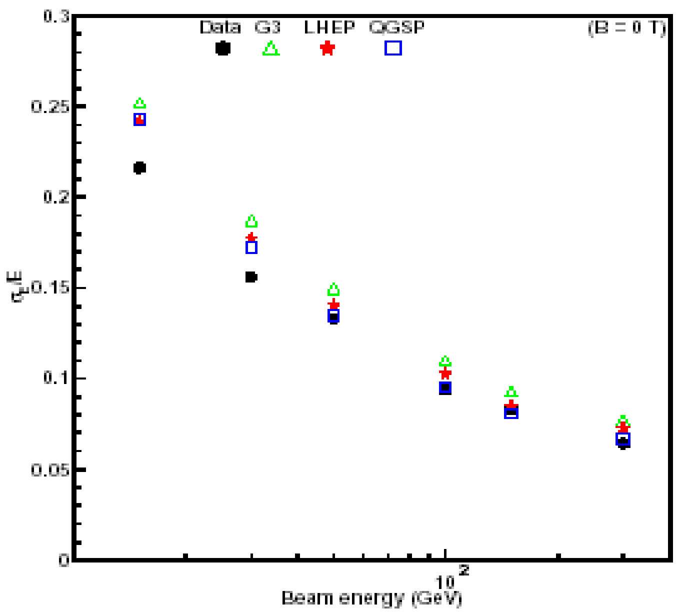


Hadronic Calorimeter (HCAL)

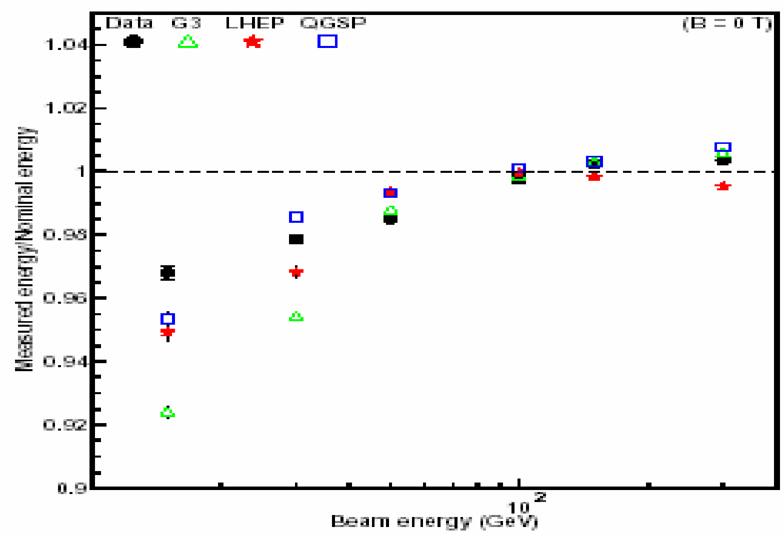
Energy resolution



Extensive validation program with comparisons to G3 and several test beam data sets, incl. combined ECAL-HCAL runs; also in context of LCG simulation physics validation project



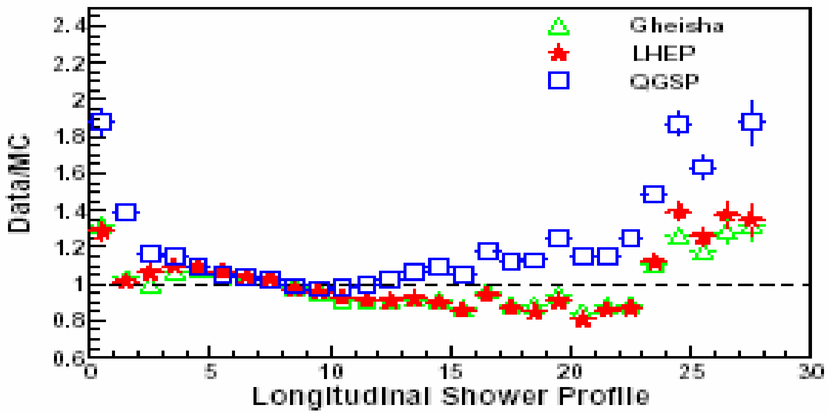
Non-linearity in energy response

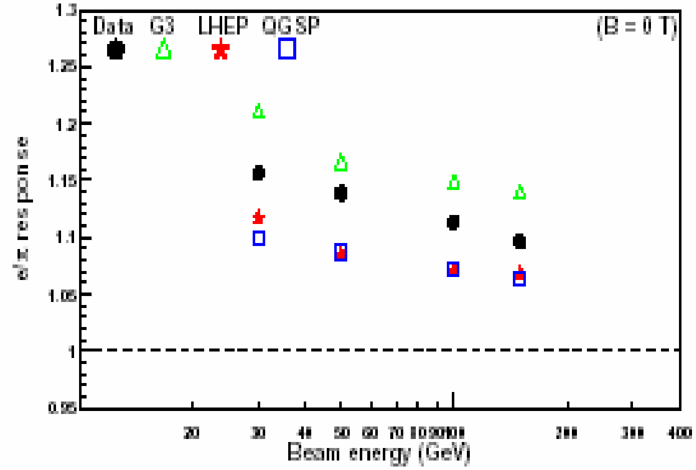


HCAL *cont'd*

e/π: G3 ~3% higher, G4 ~4% lower

Longitudinal shower profile

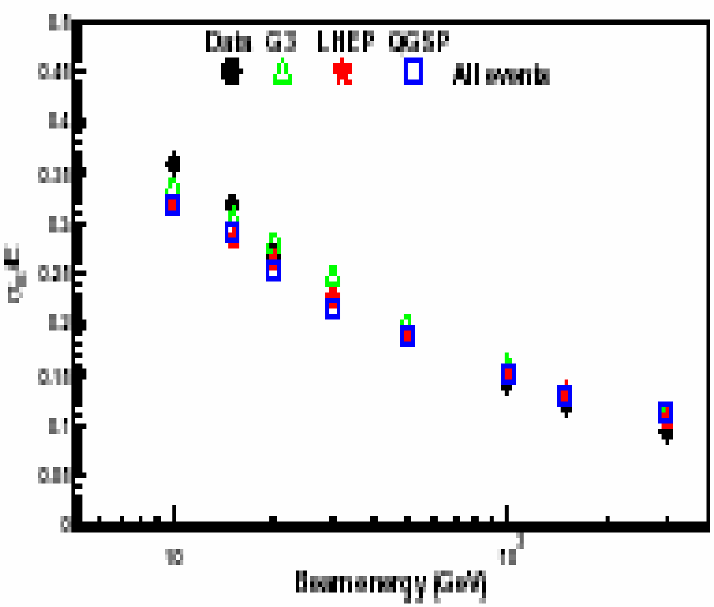


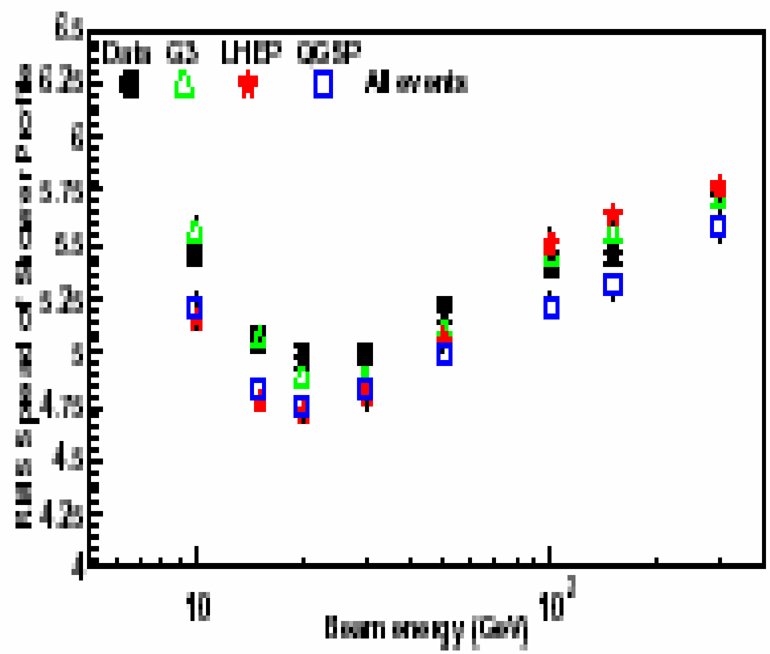


Energy resolution

ECal + HCal data

Longitudinal shower profile

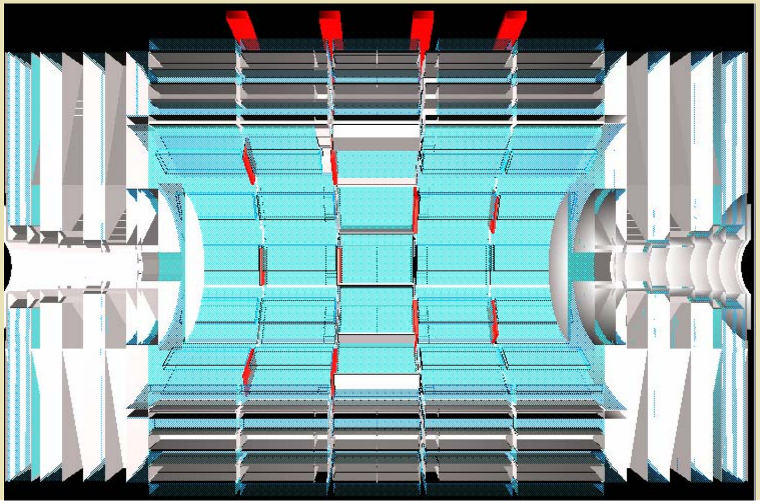


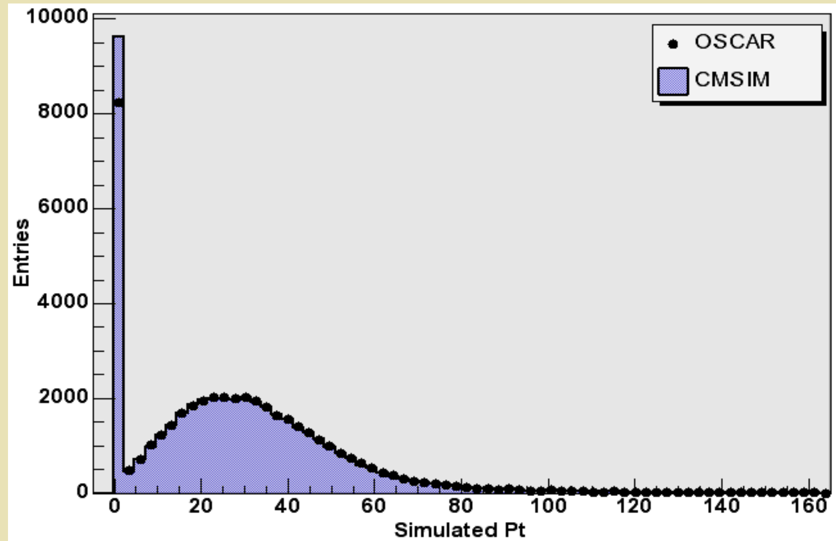


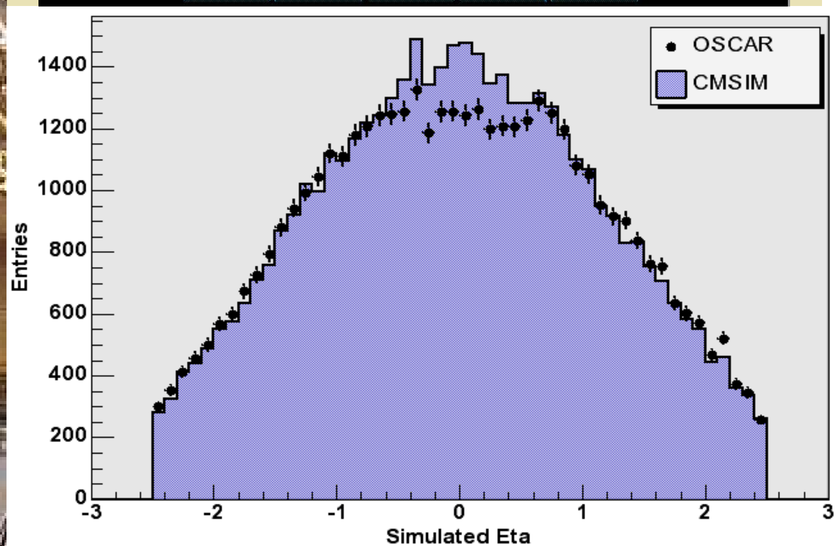
Muons

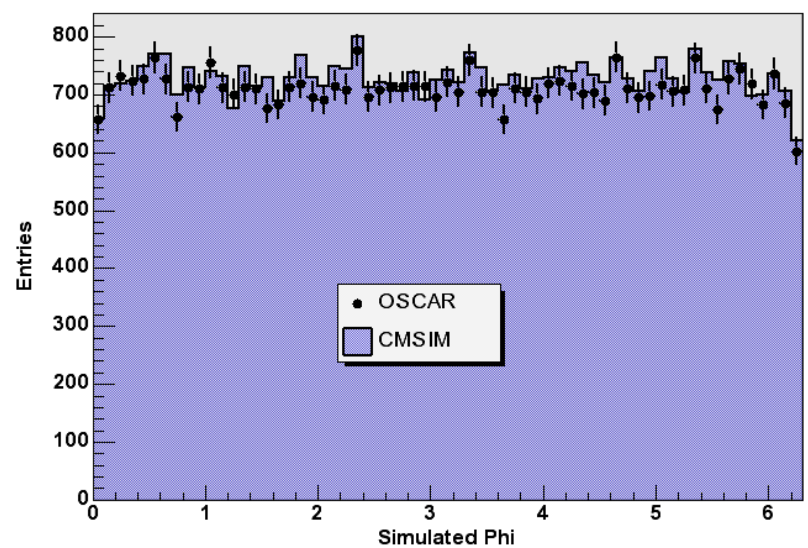
Detector and physics validation in terms of tracking and hit distributions with single μ's, Drell-Yan pairs (Mll=2TeV) and physics events H→ZZ→4μ

Muon detector layout





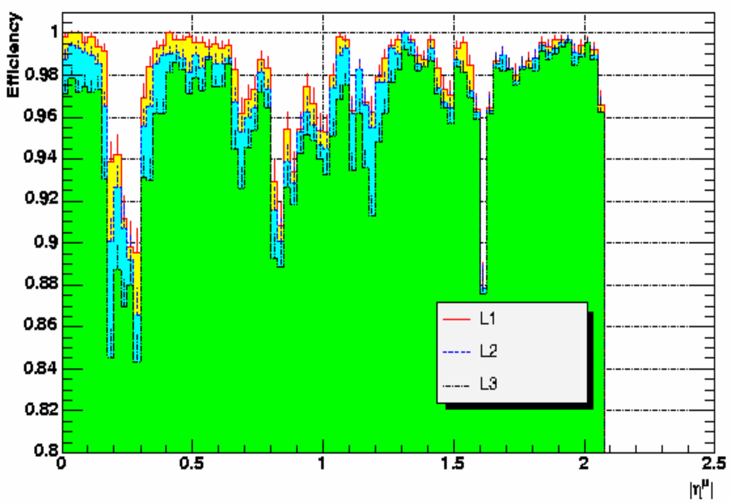




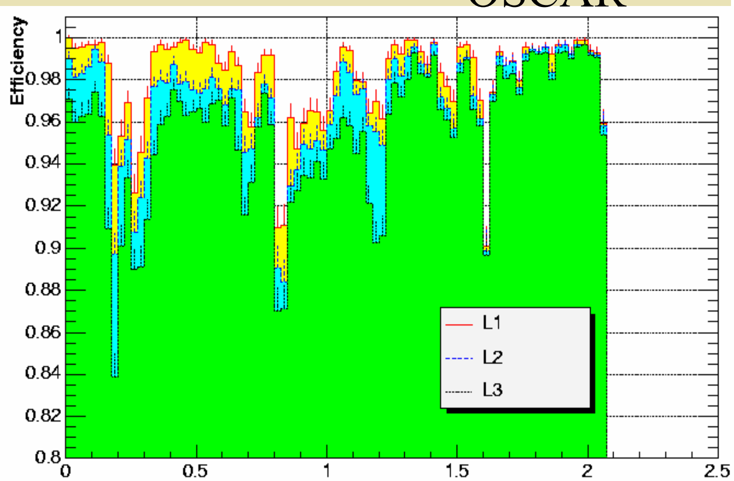
Muons *cont'd*

Trigger efficiency vs η

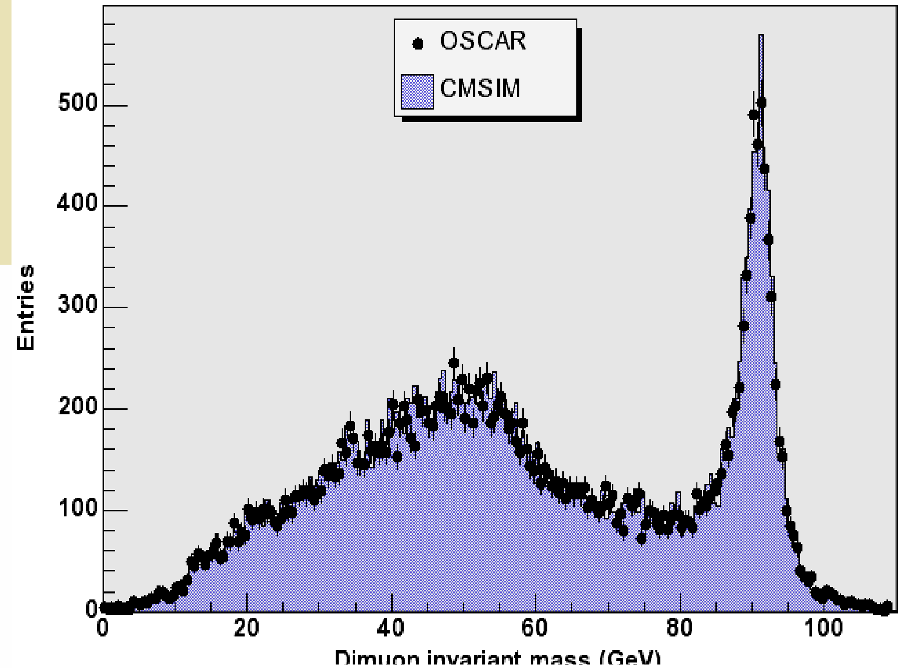
CMSIM

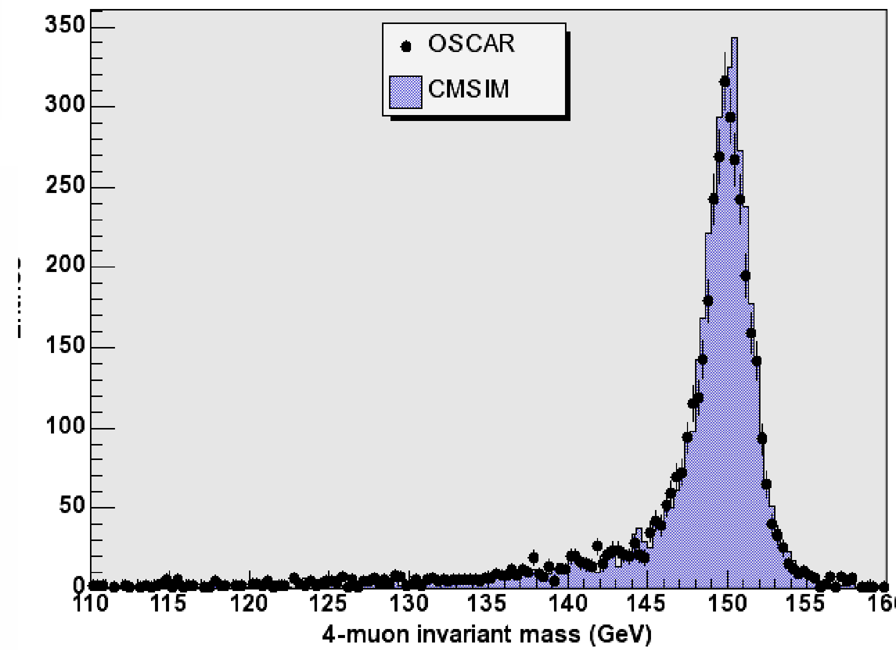


OSCAR



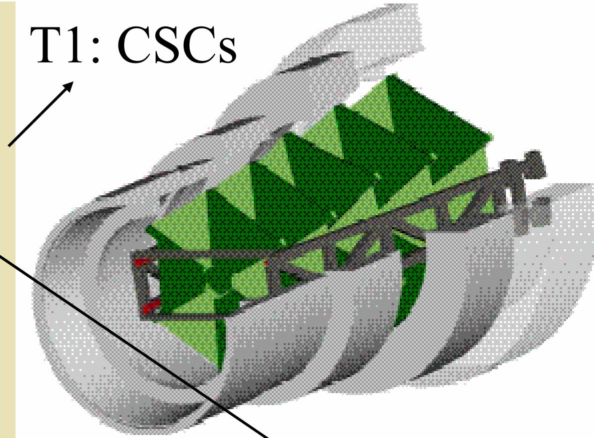
$H \rightarrow ZZ \rightarrow 4\mu$, $M_H = 150$ GeV





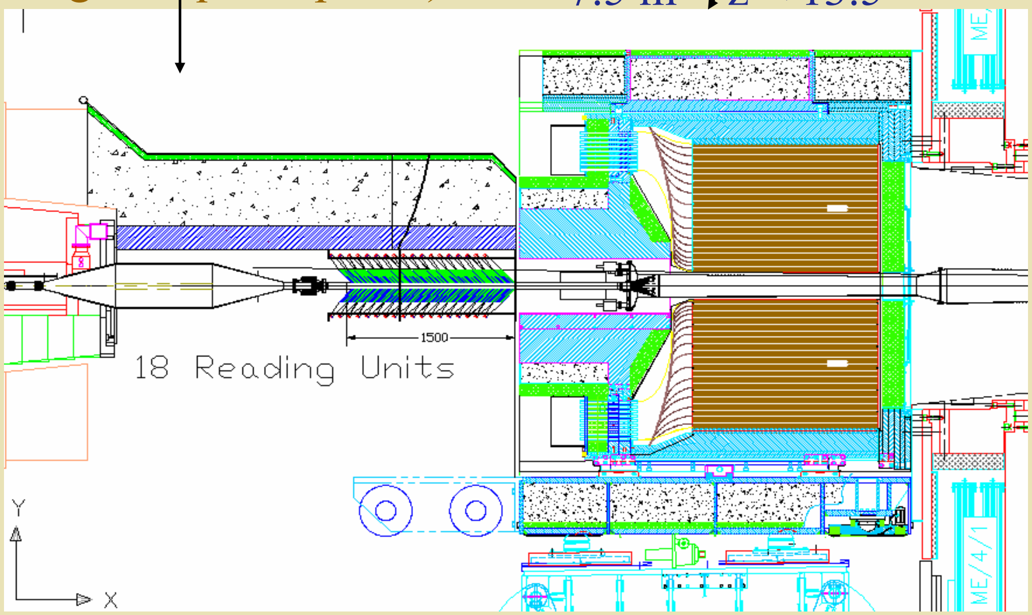
Forward Detectors

for diffractive and heavy ion physics

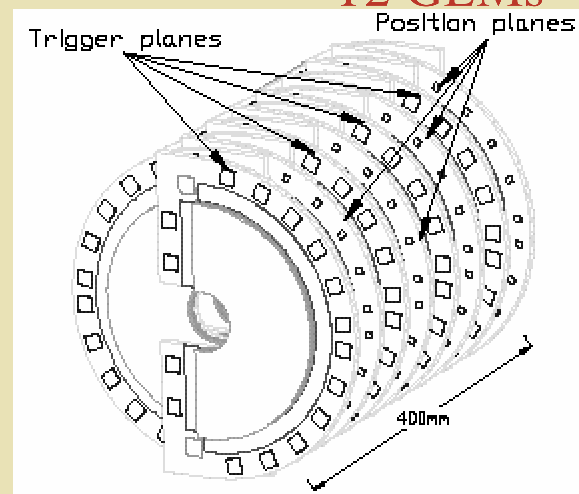


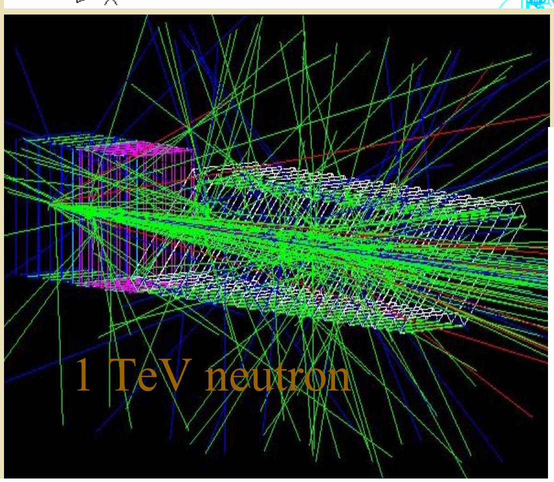
Castor Calorimeter
at 14.37 m ($5.3 < \eta < 6.7$)
(Tungsten/quartz plates)

Totem Telescopes
7.5 m < z < 13.5

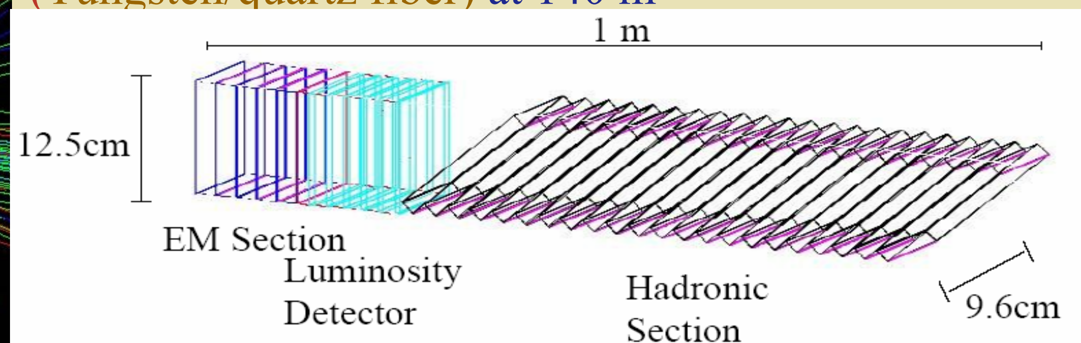


T2 GEMs





ZDC: Zero degree calorimeter
(Tungsten/quartz fiber) at 140 m



Parameterized Simulations

G4FLASH

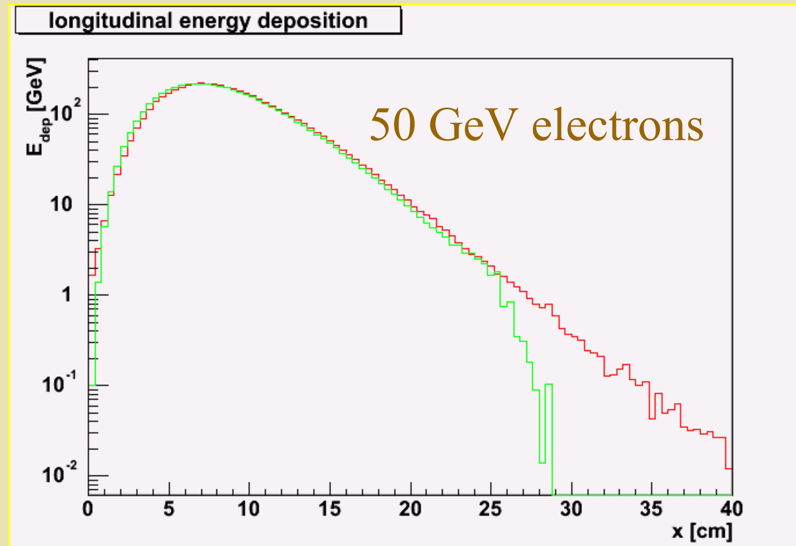
Implementation of fast EM shower simulation in Geant4/OSCAR, using GFLASH parameterized showers (spot density)

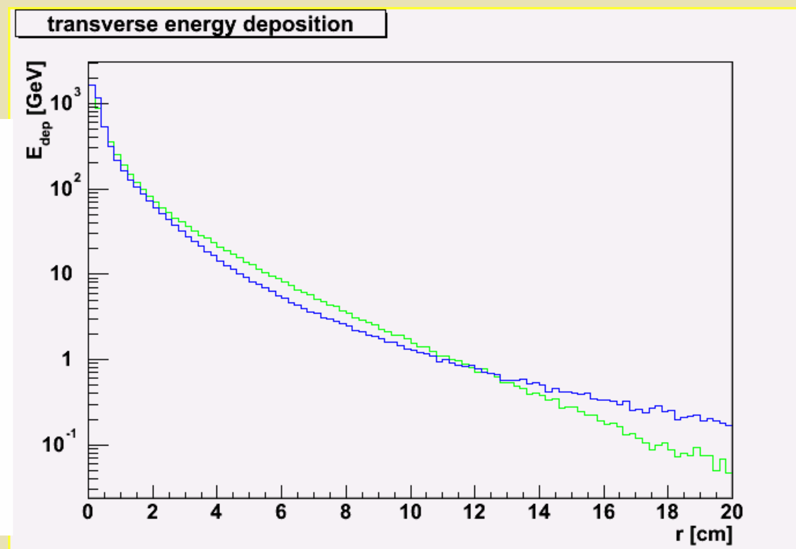
- tuning in progress…

Timing studies

Electron energy	Time/event full simulation	Time/event fast simulation
1 GeV	0.8 s	0.5 s
10 GeV	1.9 s	0.6 s
100 GeV	16 s	0.7 s
300 GeV	57 s	1.0 s

Geant4 6.2 - full vs fast





Heavy Ion Simulation

performance optimization
with a twist…

G3/CMSIM: chop event in slices of 100 tracks each and run them separately; *needed due to limitations from ZEBRA*

<u>OSCAR/Geant4:</u>
<u>run full HI events</u>

Factor 5 performance improvement by improved calorimeter track selection and hit processing

55K generated particles,
with 97K tracks from 80K vertices
kept at the end of event

Event cut in slices of 100 particles

CMSIM - G3	230 min
OSCAR_2_4_5 – G4 5.2	320 min
OSCAR_3_4_0 – G4 6.2	180 min

Full event

CMSIM - G3	Not possible
OSCAR_2_4_5 – G4 5.2	1010 min
OSCAR_3_4_0 – G4 6.2	210 min *(*)*

time/evt in given machine

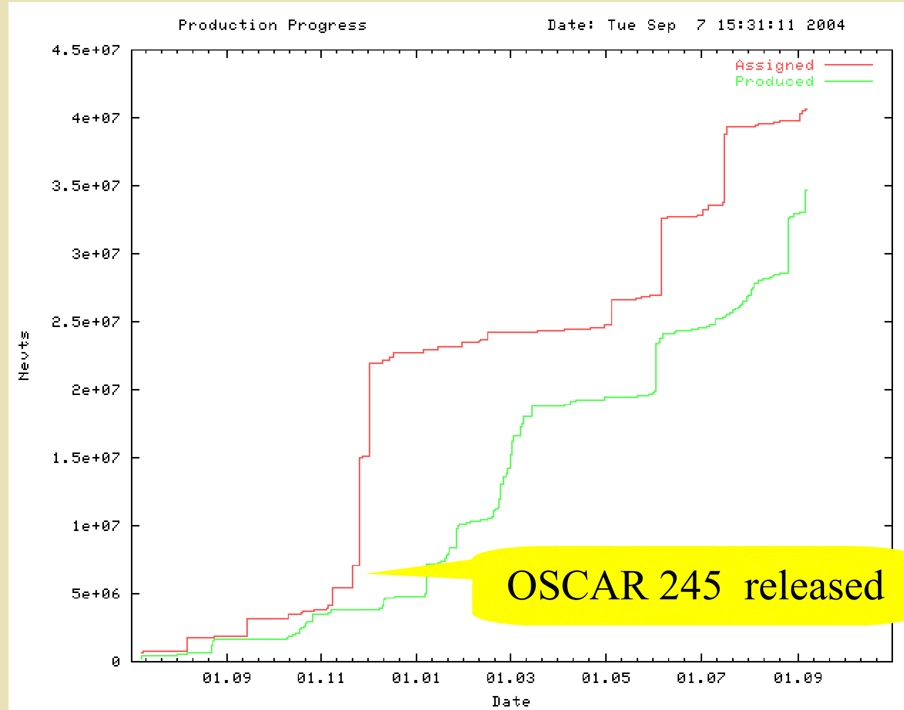
(*) 2.3 CPU hrs on P4 3.2 GHz

…effect entirely negligible in pp events!

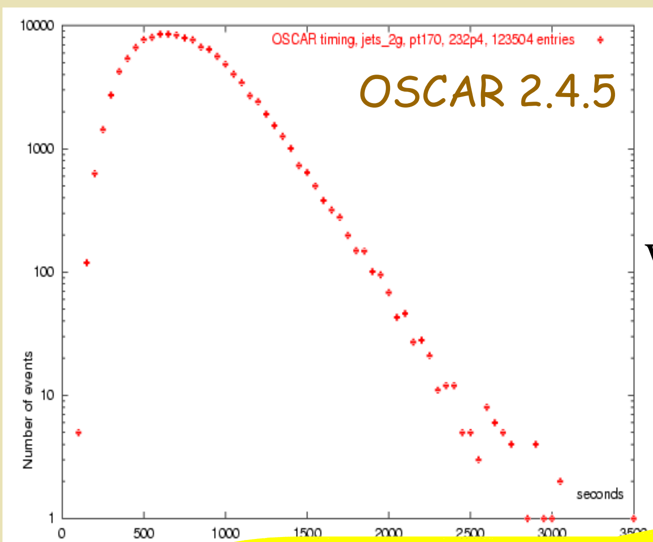
Production

OSCAR 2.4.5 in use for 10 months; longest-used version of any s/w in production; accounts for 35M of 85M events;

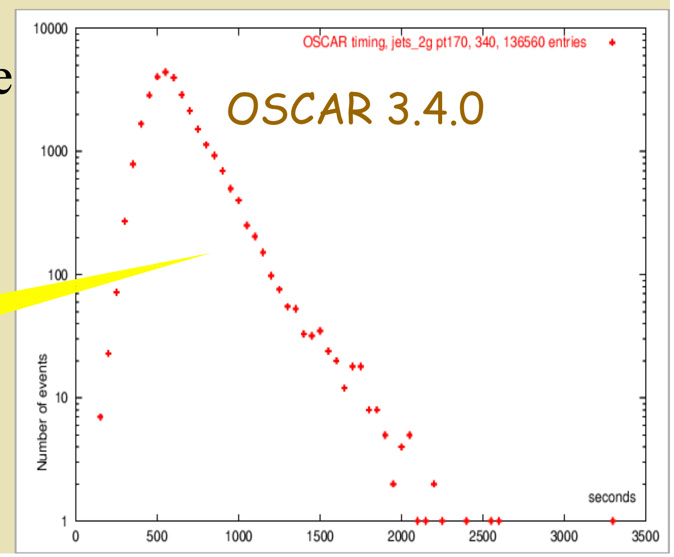
G3 simulation 'officially dead'



OSCAR 245 released



wall-clock time normalized to 1GHz CPU



Peak not moved, but tail significantly narrower. Nicer for production, easier to spot stuck jobs

Summary and Outlook

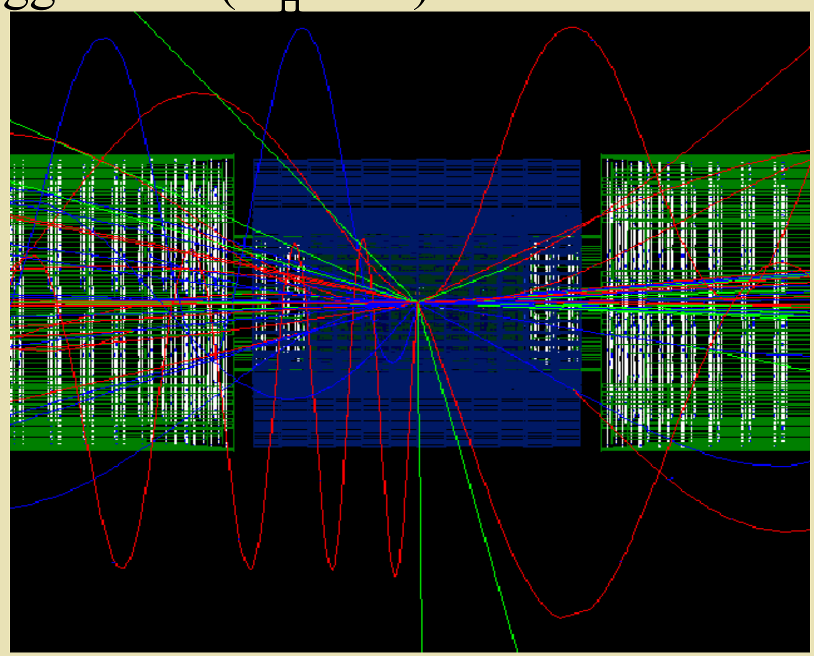
In CMS, OSCAR, the OO simulation program based on the Geant4 toolkit, has successfully replaced its Fortran/Geant3 predecessor. It has been validated and adopted by all CMS detector and physics groups. It has proven robust and performant, easily extensible and configurable.

CMS has now entered sustained-mode production:10M physics events/month through the full chain (simulation, digitization, …, DSTs)

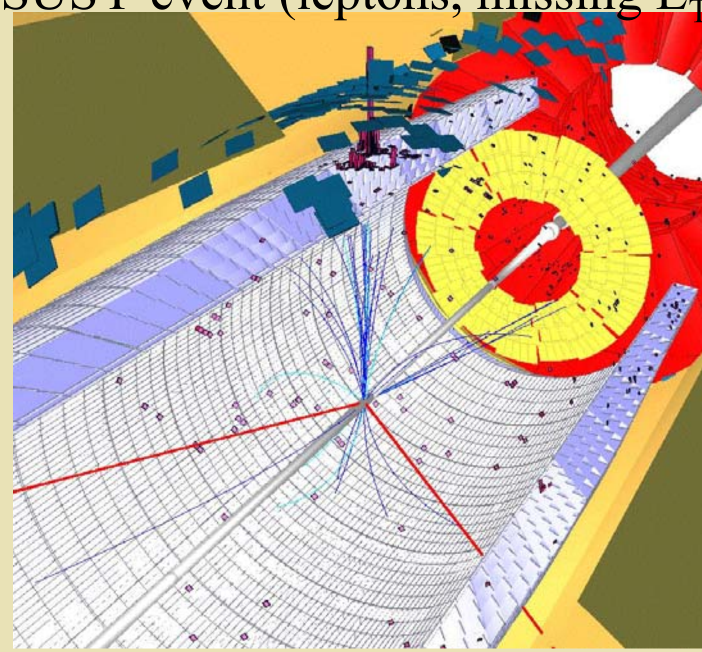
$\Rightarrow$ **A lot more good**

physics with OSCAR

Higgs event (m_H=180) in CMS Tracker



SUSY event (leptons, missing E_T)



(visualization with IGUANACMS)